Shear Strength of Fly Ash Reinforced with Non-Woven and Woven Geotextiles

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***Abstract* - Fly ash is a waste product produced from thermal power plants. The increasing production of fly ash waste is becoming a matter of global concern as its disposal operation is not only expensive but it is also hampering the environment. So it is very important to come up with the technological concepts which will ensure consumption of fly ash in bulk instead of disposing it.Geosynthetics have become well established construction materials for geotechnical and environmental applications in most parts of the world as they possess various numbers of functions which shows very positive response when used in conjunction with other earth material. It has become one of the most attractive construction materials in construction world. This paper carried out the investigation on shear strength of fly ash reinforced with woven and non-woven geotextiles in different combinations.Laboratory Direct shear test were conducted on unreinforced and reinforced fly ash. The reinforcement of geotextiles were provided in top and bottom layer, only in middle layer and then top, middle and bottom layer respectively. Reinforced fly ash showed better shear strength as angle of internal frictionvalue increases. The angle of internal friction value of raw fly ash was found to be 36^o and after reinforcement it ranges to 40.85^o, 41.15^o, 42.18^o incase of non-woven geotextile and 37.42^o, 38^o, 39^o incase of woven geotextile. Both non-woven and woven geotextile showed improvement in shear strength but most improved strength was observed in non-woven geotextile reinforcement.**

Keywords:Direct shear,fly ash, geotextiles,non-woven, reinforcement, shear strength, woven

1. INTRODUCTION

In this growing urbanization and industrialization, the greatest challenge before the industries is the disposal of the residual waste produced during the processing and manufacturing process of their products. Fly ash is disposed either in dry condition or in wet condition, but in both the ways it is hampering the environment. Thus disposal of these wastes has become a major problematic issue. And these problems need to be solved before it could cause more destruction to the environment. One of the most effective and positive way is to utilize these waste products instead of disposing. So effective uses of these industrial wastes which are used as a substitute for natural soil in the construction field will benefit the construction world in many innovative ways as it will not only solve the disposal problems but it will also helps in conservation of natural soil and at the mean time it will also lowers the cost of construction. For increasing use of fly ash as a construction material, it is very necessary to enhance its properties as fly ash alone cannot be utilized as earth material, it will have to be used in conjunction with other materials like by using various types of geosynthetics so that together it will show better and positive performance. In this project an attempt was made to evaluate the geotechnical properties of fly ash using different types of geosynthetics.

Many researchers have worked on the physical and engineering properties of fly ash and geosynthetics in order to find out their innovative use in the field of construction.Toth et al. (1978) studied the physical behavior of fly ash and found that fly ash is similar to that of silt and the structural fill made with fly ash could perform better than the fill made with natural materials. McLaren and DiGioia (1987)showed that because of the generally low value for the specific gravity of coal ash compared to soils, ash fills tend to result in low dry densities which is of advantage in the case of its use as a backfill material for retaining walls, embankments especially on weak foundation soils, reclamation of low-lying areas, etc. Singh and Panda (1996)performed a series of shear strength tests on freshly compacted fly ash specimens at various water contents and he concluded that most of the shear strength is due to internal friction. Sridharan et al. (1997) investigated the geotechnical characterization of various pond ashes in India and reported that fly ashes in general possess low unit weight, good frictional properties, and low compressibility and are well suited for their use as a structural fill. Kaniraj and Gayatri (2003) presented the geotechnical behaviour of fly ash mixed with randomly oriented fibers inclusion and found that there is a significant improvement in the shear strength parameters of fly ash. Pandian (2004)conducted various tests on fly ash and concluded that fly ash can be successfully used in the construction of embankments, roads, fill behind retaining structures etc because of its low specific gravity, freely drainage nature, ease of compaction, good frictional properties etc.Ayyappan et al. (2010) used the randomly distributed geosynthetic propylene fibers to reinforce the different soil types and concluded that there is a significant improvement in the strength parameters of soil-fly ash mixtures due to reinforcement.Geliga et al. (2010) used fly ash for stabilizing soft soil and found that there is an improved strength and better properties of soft soil sample when stabilized with fly ash.Singh (2013)conducted triaxial tests on soil reinforced with jute geotextile and found that the shear parameters (c and ϕ) of soil increases due to inclusion of jute geotextile. He concluded that the load carrying capacity of soil increases and amount of immediate settlement decreases when soil is reinforced with jute geotextile.

2. MATERIALS

Fly ash used in the present study is collected from the Kolaghat Thermal Power Station, Kolaghat, West Bengal, India. The most common chemical compositions of fly ash are SiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, organic carbons and others. The fly ash is Class F fly ash, greyish in colour and pozzolanic in nature.

In the present investigation, two different types of geosynthetics were studied i.e. woven and Non-woven geotextiles collected from various suppliers and used in various layers. The geotextiles used are shown in Fig. 1and Fig. 2.The materials used and also thereinforcement provided in different layers in this present study are designated as follows:
FA: Fly ash collected from Kolaghat Thermal Power Station
GT: Geotextile
NW: Non-woven geotextile
W: Woven geotextile
L1: NW+FA+NW
L2: FA+NW+FA+NW+FA
L3: NW+ FA+NW+FA+NW+FA+NW
L4: W+FA+W
L5: FA+W+FA+W+FA
L6: W+ FA+W+FA+W+FA+W

Fig. 1. View of woven geotextile

Fig. 2. View of non-woven geotextile

Table 1 Propertiesof geosynthetics (Produced by suppliers)

Geotextile type	Nominal mass per unit area (g/m2)	Thickness (mm)	Tensile strength (N/m)
Non-woven	250	2.2	8
Woven	-	-	25

3. SAMPLE PREPARATIONS

The samples used in the present investigation were prepared at its own OMC and MDD obtained from standard compaction test as per ASTM D 698-07. Both woven and non-woven geotextiles were first cut in the same dimension equal to the shear box i.e. (6×6) cm and then used as reinforcement and finally Direct shear test is conducted on prepared samples. The geotextiles were placed as reinforcement form in different layers. Numbers of studies on fly ash were made providing different types of layers of reinforcement using both woven and non-woven geotextiles. Reinforcement used in different layers is shownin Fig 3 and 4.

Fig. 3. FA+GT+FA+GT+FA

Fig. 4. GT+FA+GT+FA+GT+FA+GT

Fig. 5. GT+FA+GT

4. EXPERIMENTAL PROGRAM AND RESULTS

Different experiments have been carried out as per ASTM standards. The tests which were carried out both on raw fly ash and reinforced fly ash for determining physical properties and engineering properties are as follows.

- Specific Gravity Test (ASTM D 854-06)
- Grain Size Analysis by Hydrometer (ASTM D 422-63(2007))
- Standard Proctor Compaction Test (ASTM D 698-07)
- Direct shear Test (ASTM D 6528-07)

4.1 Specific Gravity (G) of fly ash

The specific gravity test was conducted on raw fly ash as per ASTM D854-06. Several numbers of trials were made and specific gravity (G) of fly ash was found to be 2.13 which are lower than the conventional earth material.

4.2 Grain Size analysis of fly ash

Grain size analysis by hydrometer has been conducted on fly ash as per ASTM D 422-63-07 and from the test the sand size particle, silt size particle and clay size particle was found which are tabulated in Table 2. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) for Fly ash were found to be 3.889 & 0.917 respectively, indicating uniform gradation of samples. Graph showing grain size distribution curve is shown in Fig.6.

4.3Standard Proctor Compaction Test

The light compaction test was conducted on fly ash as per ASTM D 698-07 in order to find optimum moisture content (OMC) and maximum dry density (MDD) of fly ash and from the test result we can see that the OMC and MDD of fly ash is 26.8% and 11.98 KN/m^3, which has been tabulated in Table 3. A graph showing dry density versus water content is shown in Fig. 7.

4.4 Direct Shear Test

Direct shear test as per ASTM D 6528-07 were conducted on fly ash and fly reinforced with different types of geosynthetics in order to find the cohesion and angle of internal friction of fly ash with and without reinforcement. The Φ and C value of fly ash and fly ash reinforced with different types of geotextiles in different layers are given in details in Table 4 and the relevant graphs are presented in Fig. 8 to Fig. 15.

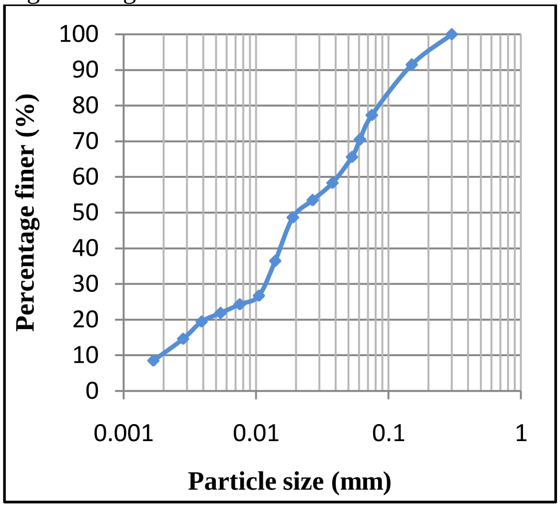

Fig. 6. Grain size distribution curve of fly ash

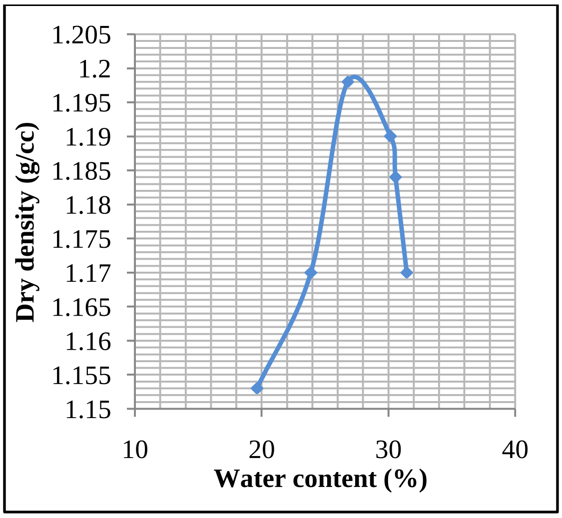

Fig. 7. Dry density versus water content curve

5. RESULTS AND DISCUSSIONS

Experimental tests results obtained after performing different laboratory tests to determine physical and engineering properties of fly ash are shown in Table 2 and 3. Shear parameters of raw and reinforced fly ash are highlighted in Table 4 and percentage increase in shear strength and peak stress are presented in Table 5 and 6. In this section detail discussions have also been made based on the experimental tests results. The effect of non-woven and woven geotextile on shear parameters of fly ash,stress-strain behaviour of fly ash with non-woven and woven geotextile, effect of number of layers of reinforcement on internal friction (ф) of fly ash, effect of number of layers of reinforcement on vertical deformation of fly ash are highlighted in this section.

Table 2 Physical Properties of Fly Ash

Physical properties	
Properties	Test results
Specific Gravity (G)	2.13
Sand Size particle (%)	14.17
Silt Size particle (%) (%)	77.33
Clay Size particle	8.5
Plasticity Index, PI (%)	NON PLASTIC
Coefficient of Uniformity, C_U	3.889
Coefficient of curvature, C_C	0.917

Table 3 Engineering Properties of Fly Ash

Engineering properties	
Properties	Test Results
Maximum dry density (kN/m^3)	11.98
Optimum moisture content (%)	26.8
Angle of internal friction (degree)	36
Cohesion (kPa)	0.393

5.1 Effect of Non-woven and Woven Geotextile on Shear Parameters of Fly Ash

TheΦ value and C value of unreinforced and fly ash reinforced with non-woven and woven geotextile in different layers are given in Table 4 and shear stress versus normal stress plots of fly ashand reinforced fly ash are presented in Fig. 8 and 9 and from figures, we observed that there is an increase in Φ value when both woven and non-woven reinforcement were provided, which implies that after providing reinforcement the shear strength of fly ash increases. Fly ash is weak in tension and geotextile has good tensile strength. When geotextile comes in contact with fly ash the friction angle of the system increases and gives a better internal friction. The geotextile will also act as binding or interlocking material. Singh (2011 and 2013) illustrated that the improvement in strength parameters of fly ash is due to the fact that reinforcement provided into the fly ash improves its load-deformation behaviour by interacting with the fly ash particles mechanically through surface friction and also by interlocking. Through interlocking the stress from the fly ash is transferred to the reinforcement and hence the load bearing capacity of fly ash increases. Higher the Φ value greater will be the shear strength. Latha and Gayatri (2007) also illustrated that geotextile reinforcement increases the Φ value and improves the shearing strength. The most improved Φ value was observed in case of non-woven geotextile as woven geotextile has the least friction, although it has the greatest stiffness and strength among all types of geotextiles as per Tuna and Altun (2012). From figures and tables it is observed that with increase in normal stress, shear strength also increases. The percentage variations in shear strength are highlighted in Table 5. Variations in Φ and C value when reinforcement is placed in different layers are shown in Table 4.

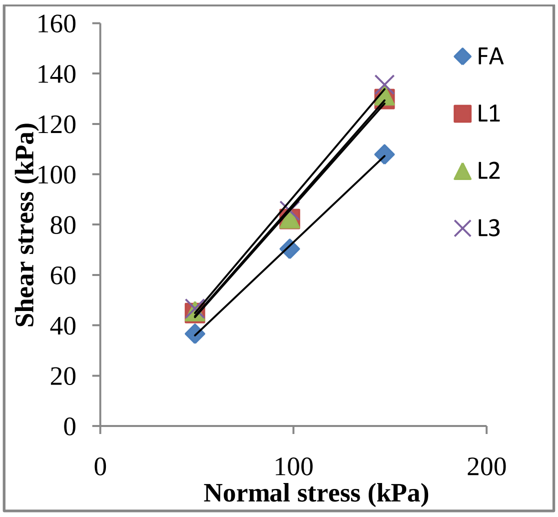

Fig. 8. Shear stress versus Normal stress of unreinforced fly ash and fly ash reinforced with non-woven geotextile

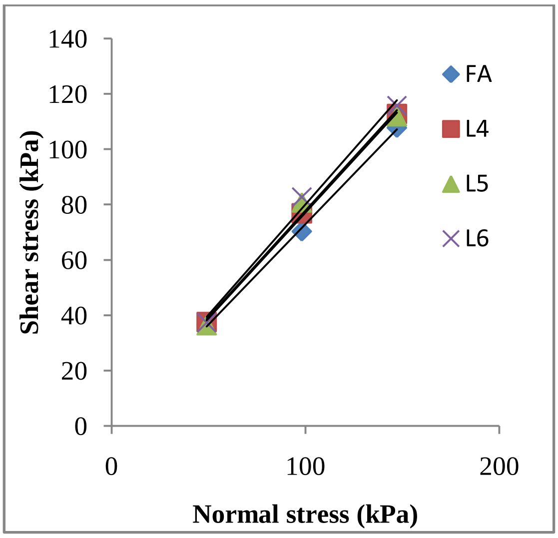

Fig. 9. Shear stress versus Normal stress of unreinforced fly ash and fly ash reinforced with woven geotextile

Table 4 Shear parameters of fly ash and fly ash reinforced with geotextiles

	Cohesion, C (kPa)	Angle of internal friction,Φ (in degrees)
F.A.	0.393	36
Reinforced with non-woven geotextile		
L1	0.686	40.85
L2	0.693	41.15
L3	0.350	42.18
Reinforced with woven geotextile		
L4	0.583	37.42
L5	0.843	38
L6	0.163	39

Table 5 Percentage increase in shear strength of reinforced fly ash

Fly ash reinforced with Non-woven geotextiles			
Normal stress (kPa)	L1 (%)	L2 (%)	L3 (%)
49.05	19.6	20.87	24.3
98.1	19.33	20.6	24.6
147.15	19.22	20.5	24.7
Fly ash reinforced with woven geotextiles			
Normal stress (kPa)	L4 (%)	L5 (%)	L6 (%)
49.05	5.8	7	10.8
98.1	5.5	6.86	11.55
147.15	5.5	6.24	9.62

5.2 Stress-Strain Behaviour of Fly Ash with Non-woven and Woven Geotextile

The stress-strain curves of unreinforced fly ash and fly ash reinforced with nonwoven geotextile are plotted and have been presented in Fig. 10 to 12.From stress-strain curve it was seen that the fly ash used was in loose condition at the time of experimental test as the nature of curve shows a gradual increase in shear stress at first and finally attains a constant value. After reinforcement was provided in different layers, it still remains in loose condition; however their peak stress increases when reinforcement was provided. The highest peak stress was observed when woven geotextile was used as reinforcement in total 4 layers as shown in Fig. 4 i.e. in top, middle and bottom layer. The increase in peak stress indicates that there is an improvement in shearing strength after reinforcement. The geotextile works as a friction and tension resisting element which in turns improves the strength of fly ash. The percentage variations in peak stress of unreinforced and reinforced fly ash are highlighted in Table 6.Kumar and Sridhar (2013) also found similar trend after inclusion of coir mat reinforcement. The highest percentage increase in peak stress was observed in the reinforcement provided in 4 layers i.e. in top, middle and bottom layer. Nguyen et al. (2013) also illustrated that geotextile as reinforcement improves stress–strain performance in terms of increasing peak stress which in turns increases the shear strength.

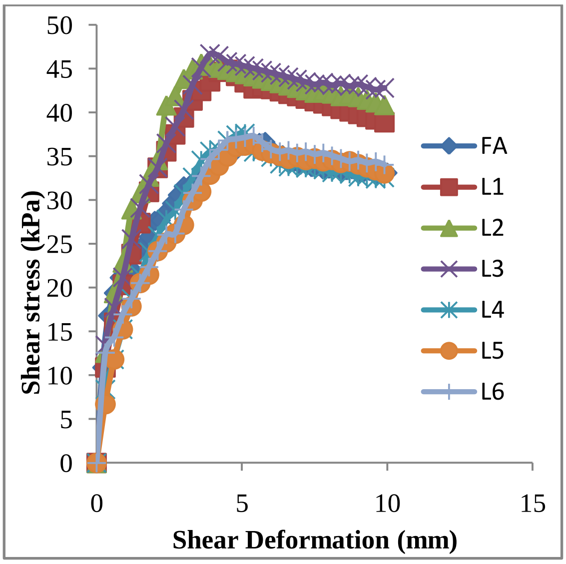

Fig. 10. Stress-Strain curve of unreinforced and reinforced fly-ash @ 49.05 kPa.

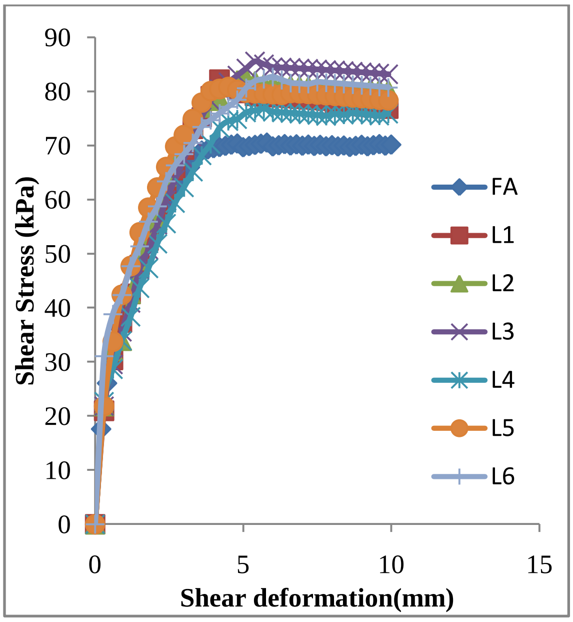

Fig. 11.Stress-Strain curve of unreinforced and reinforced fly-ash @ 98.1 kPa.

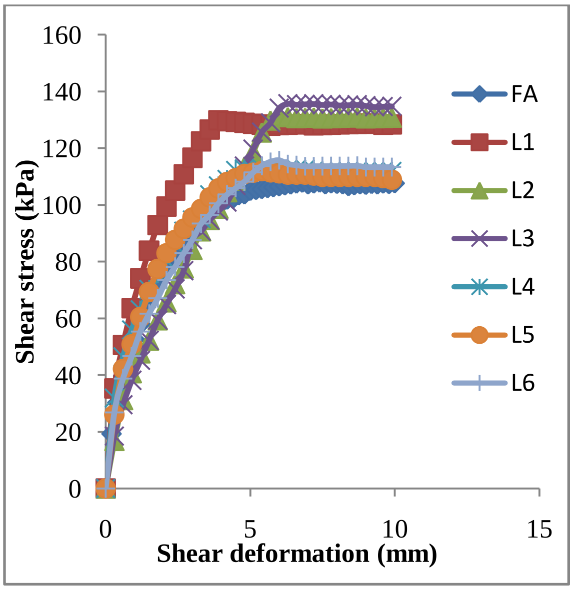

Fig. 12.Stress-Strain curve of unreinforced and reinforced fly-ash @ 147.15 kPa.

Table 6 Percentage increase in peak stress of reinforced fly ash

Reinforced with Non-woven geotextile			
Normal stress (KPa)	L1 (%)	L2 (%)	L3 (%)
98.1	14	15	18
147.15	17	18	21
Reinforced with Woven geotextile			
Normal stress (KPa)	L4 (%)	L5 (%)	L6 (%)
98.1	8	13	15
147.15	4	5	7

5.3 Effect of Number of Layers of Reinforcement on internal friction (Φ) of fly ash

The tests were conducted by providing three different layers of reinforcement of both woven and non-woven geotextiles. From the results obtained after completion of direct shear test number of variations in shear parameters were seen at different layers of reinforcement which are highlighted in Table 4. It was seen that Φ value increases when reinforcement was provided and there was a variation in Φ value when reinforcement was provided in different layers. The improvement in shear parameters is due to the reinforcement provided. The most improved value in strength was observed in 2nd trial i.e. reinforcement provided in top, middle and bottom layers. The improvement in strength seen may be because of the number of layers of reinforcement provided i.e. in total four layers. Singh (2013) illustrated that most increased Φ value was found in case of 4 layers of reinforcement. Since layers were more, internal friction between the geotextiles and fly ash will be more and hence strength increases. Higher the number of layer of reinforcement higher will be the angle of internal friction. As per Singh and Panda (1996) most of the shear strength is due to the internal friction.

5.4 Effect of number of layers of reinforcement on vertical deformation of fly ash

The plots between vertical deformation and shear deformation of unreinforced and fly ash reinforced with non-woven and woven geotextiles are presented in Fig. 13 to 15. From figures, it was seen that the inclusion of non-woven reinforcement deteriorates the load-deformation behaviour of fly ash. The vertical deformation is more when non-woven reinforcement was provided. The deterioration may be because of the nature of geotextile which is very soft and spongy and so it has the tendency to deform more when stress is applied. However when woven reinforcement was provided, the vertical deformation decreases. The most improved load-deformation behaviour was seen in fly ash reinforced with 4 layers of geotextile reinforcement i.e. top, middle and bottom layers. Nazari and Moayed (2011) studied the effects of geosynthetics on two layered soil and illustrated that geosynthetics improves the bearing capacity and decreases the vertical deformation of soil. Singh (2013) also illustrated that geotextile reinforcement improves the bearing capacity of fly ash and reduces its immediate settlement and therefore vertical deformation decreases eventually.

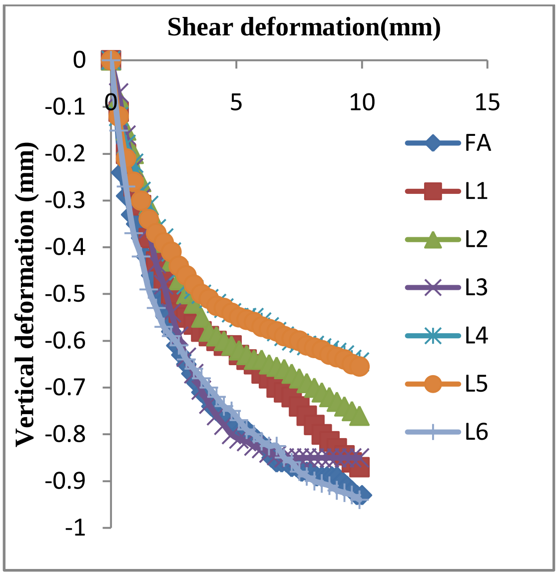

Fig. 13. Vertical deformation versus Shear deformationof unreinforced and reinforced fly ash @49.05 kPa.

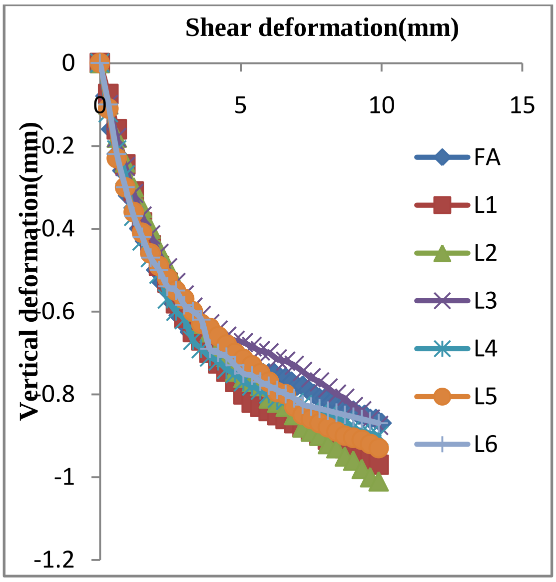

Fig. 14. Vertical deformation versus Shear deformationof unreinforced and reinforced fly ash @98.1 kPa.

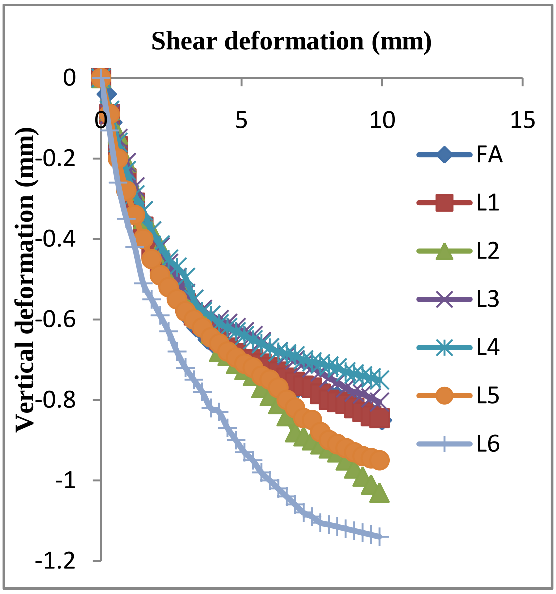

Fig. 15.Vertical deformation versus Shear deformationof unreinforced and reinforced fly ash @147.15 kPa.

6. CONCLUSIONS

The following conclusions may be made based on the experimental tests results and discussions.

- When fly ash was reinforced with woven and non-woven geotextile its Φ value increases. Since fly ash achieves most of its shear strength from internal friction and it exhibits very negligible cohesion, it may be concluded that reinforcement enhances the shearing strength of fly ash.
- Geotextile as reinforcement improves stress-strain performance by increasing peak shear stress which will improve the properties of fly ash to resist against shear.
- As the number of layers of reinforcement is increased its shear strength also increases.
- The vertical deformation of fly ash decreases in case of fly ash reinforced with woven geotextiles whereas incase of non-woven geotextile, rather increases vertical deformation and it may be because the geotextile is very soft and spongy type material.

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